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JOINT FIT-UP TOLERANCES & ADAPTIVE CONTROL FOR GAS-TUNGSTEN-ARC ROOT-PASS ALL-POSITION PIPE WELDING

Report No 87-125-K

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ABSTRACT

Mechanized pulsed-current gas-tungsten-arc (P-GTA) all position root-pass pipe welding procedures have been developed for a wide range of weld joint fit-up conditions. The present work illustrates that the joint fit-up tolerance for mechanized P-GTA root-pass welding can be greatly increased by incorporating adaptive control capabilities into existing mechanized welding systems. Guidelines for the development of a computer-based and sensor-equipped pipe welding system have been discussed. Tentative control algorithms for adaptive P-GTA root-pass pipe welding have been established. The requirements and current progress for the development of a laser-based sensor system have been described.

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EXECUTIVE SUMMARY

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As part of its Automated Pipe Welding Program, the Welding Unit is investigating appropriate means and approaches to improving existing mechanized pipe welding systems for field pipe welding applications.

All-position pulsed-current gas-tungsten-arc (P-GTA) welding procedures have been developed for root-pass welding of a wide range of weld joint fit-up conditions. It has been illustrated that root-pass welding, which is presently carried out mostly by manual GTA welding, can also be performed using mechanized P-GTA welding by incorporating adaptive control capabilities into existing mechanized welding systems. Guidelines have been established for the development of a computer-based P-GTA welding system equipped with a laser-based sensor system, which can be used for adaptive control root-pass welding. Control algorithms for interactive adjustments and optimization of welding parameters depending on the varying welding conditions have been outlined. The requirements and current progress in the development of a laser-based sensor system have been discussed.

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To DR. D. MILLS
Director of Research

JOINT FIT-UP TOLERANCES & ADAPTIVE CONTROL FOR GAS-TUNGSTEN-ARC ROOT-PASS ALL-POSITION PIPE WELDING

1. INTRODUCTION

As part of the Automated Pipe Welding Program/1/, the Welding Unit of the Metallurgical Research Department is carrying out research studies to improve existing mechanized pipe welding procedures and systems for field welding of large diameter piping in Ontario Hydro. It is known that root-pass welding using programmable mechanized pipe welding machines requires precise weld preparation geometry, and very accurate fit-up between the mating parts. Rough preparations and approximate fit-up are completely unacceptable for mechanized welding. Usually, pipe ends can be prepared to close tolerances, but obtaining good fit-up and alignment is always problematic, especially when performing pipe tie-ins (final joints between pipes fixed at the other ends).

In 1985, an extensive survey was performed by the Welding Unit of the Metallurgical Research Department and AECL/SPEL regarding recent advances in computer-controlled welding technology, orbital sensor systems, welding systems and sensor technology/2/. The survey suggested that present mechanized pulsed-current gas-tungsten-arc (P-GTA) welding capabilities can be enhanced by adding some level of computer intelligence and sensor-based adaptive feedback to measure and adjust for unpredictable changes of weld geometry and weld joint fit-up conditions. For performing adaptive control P-GTA root-pass welding, it is necessary to develop a welding data base and a control strategy for suitable adjustments of welding parameters to accommodate weld joint fit-up variations.

Subsequently, a research project was contracted to AECL/SPEL in 1985 to preliminary investigation of the use of adaptive control techniques to improve the ability to weld pipe joint fit-up variations with P-GTA welding/3/. The preliminary test results indicated that the maximum root opening or misalignment that could be welded using an OH mechanized P-GTA welding procedure (eg, PA-671) was of the order of 0.76 to 1.02 mm (0.03 to 0.04 inches), and was somewhat less if both factors were present simultaneously. Modifications to the procedure were found to permit welding of 1.59 mm (1/16") root opening or misalignment. It was found that when the root faces of the joint were separated beyond this amount, the

metal melted by the arc failed to flow together and bridge the gap, but instead "balled up" on each side of the preparation under the influence of the surface tension. Furthermore, P-GTA root-pass welding studies at AECL/SPEL were only carried out in the 1G and 2G welding positions.

In the present work, all-position P-GTA root pass welding studies were carried out by the Welding Unit to achieve the following objectives:

a) to develop all-position P-GTA welding procedures for a wide range of weld joint fit-up conditions and to determine the tolerance of the mechanized P-GTA welding process to joint fit-up variations, assuming a consistent machined land thickness (counterbored pipe);

b) to determine suitable adjustments of welding parameters to permit the extremes of joint fit-up to be welded (ie, weld joint fit-ups that can be welded using manual GTA welding practice);

c) to establish suitable control strategies for adaptive control of P-GTA root-pass pipe welding;

d) to identify necessary enhancements to existing mechanized P-GTA welding systems (ie, in terms of computer intelligence and sensor systems) that would be required for performing adaptive feedback control of root-pass pipe welding.

2.0 EXPERIMENTATION

2.1 Material and the Weld Joint Design

The carbon steel plate used was specified to conform to ASME SA-285 Gr C material in 12.7 mm (0.5 inch) thickness. The test plates were sheared to a size of 200mm x 75mm (8 in x 3 in). The weld preparation was machined onto one long edge of each plate by milling. The "J" type weld preparation (see Figure 1) consisted of a 9.5 mm (3/8 inch) radius and a 2.4 mm (3/32 inch) machined land. The relatively large radius allowed space for greater weave maneuverability of the welding torch in the root region than is allowed in a more conventional "J" prep.

Prior to all the welding trials, the test plates were lightly ground to remove burrs and surface scale and were degreased with acetone. Two plates were then clamped in such a way to obtain the specific root opening/misalignment combinations with the use of shims and spacers. The clamped plates were then tack welded manually using the GTA welding process.

The filler metal used in the mechanized welding trials conformed to ASME Classification SFA 5.18 (ER 70S-3). A 0.9 mm (0.035 inch) diameter wire was used.

2.2 Welding Equipment

A Dimetrics Gold Track II pipe welding system was used in the present work. This system consists of a pulsed-current gas-tungsten-arc welding (P-GTAW) power source with controls for a mechanized welding head. The details of the control panel, displaying the control functions and ranges of these functions are shown in Figure 2. The control functions for the welding head include automatic-voltage-control (AVC) of the arc length, pulsed welding current control, pulsed wire feed control, and synchronized torch travel and oscillation controls.

As shown in Figure 2, there are three carriage travel control modes. In the present work only the continuous travel mode and the background step travel mode were used.

The continuous travel mode can be used with and without the oscillator motion. The wire feed rates are individually controlled, and timed to coincide with the pulsation of the current. When the oscillator motion is used, the primary current is present only during the side dwells of the oscillator motion. Separate left and right dwell times are programmable. The background current level was used during the oscillator excursion period.

A background step travel mode was also used with oscillator motion. Here the linear travel of the carriage takes place only during the period that the oscillator is in dwell. Although the travel speed is set relatively high, the average speed over a fixed distance is still relatively low because of the small percentage of the time that the torch is in the dwell period. The lateral weave speed is set by controlling the time the torch has to traverse across the amplitude of the oscillation pattern. Here again the primary current is present only during the dwell periods and the background is used during the torch oscillation or excursion period. The pulsing wire feed rate is synchronized with the pulsing of the welding current levels.

Two different AVC control modes were used for arc length adjustments:

a) Continuous Sampling mode - in this mode the arc voltage is sampled both during the primary current periods and the background current periods and the arc length is continuously being corrected.

b) Primary Current Sampling Mode - in this mode the arc voltage is sampled and the arc length is corrected only during the primary current level. The AVC control is locked during the background current level and the electrode is held at a fixed distance during oscillator traverse.

A rotating positioning table was designed and used in the present work. A flat welding carriage track was mounted onto the table, either parallel or perpendicular to the axis of the table rotation. The welding test plates were then clamped parallel to the carriage track. By rotating the table, the operator could obtain the following welding positions: 1G (flat), 2G (horizontal), 3G (vertical) and 4G (overhead). In the present work, 2% thoriated, 2.4 mm(3/32 inch) tungsten electrode was used in all the welding trials. The tips of the electrodes were ground to a 24 degree included angle. The torch shielding gas was argon flowing at a rate of 14.2 l/min (30 cfh). No backing gas or root shielding was used.

2.3 Welding Trials and Test Results

Prior to mechanized welding, some of the test plates were welded manually to establish approximate ranges of welding current for different fit-up conditions. Furthermore, all the mechanized welds were made starting from manual tack welds. This starting procedure was found to be necessary to establish a stable weld pool, especially in the presence of relatively large root gap.

Weld samples were made under a wide range of welding joint fit-up conditions (see Table 1) in the 1G, 2G, 3G(up), 3G(down) and 4G welding positions. The main objective of these welding trials was to develop sets of welding parameters for specific fit-up conditions. This was achieved on practice runs through a process of trial and error. For the initial welding trials, approximate welding parameters were selected, then fine-tuned to produce a stable weld bead over the length of the test plate (ie, approximately 100 mm). Improper welding parameter settings would manifest by a collapse of the weld pool, unfused edges and other apparent discontinuties. Besides visual examination, three cross-sections were taken from each representative weld sample and were prepared for metallographic examination.

The welding procedures which produced stable root-pass welds for various combinations of fit-up conditions/welding positions, are shown in Table 2 to Table 8. Cross-sections of representative weld samples are shown in Figures 3 to 9.

2.3.1 General Root Bead Quality

As shown in Figures 3 to 9, all the root beads which were produced using the "fine-tuned" welding procedures developed in the present work, were free from any weld defects such as inadequate fusion and dimensional discrepancies such as weld metal suck-back or excessive weld sag (see Figures 4 to 9). It was noticed that the root bead surface at the underside was often coated with a heavy oxide scale. Furthermore, for weld joint fit-ups containing misalignment, the root bead displayed sharp changes of internal slope.

2.3.2 Effects of Root Opening

It was shown in previous work at AECL/SPEL/2/ that the ability to produce sound P-GTA root-pass welds was hampered by root opening variations and that suitable adjustments to the welding parameters must be made to compensate for these changes. In the present work, P-GTA root-pass welds 1 to 14 were attempted with root openings ranging from 0 to 6.4 mm (0 to 1/4 inch) in all welding positions. These weld joints contained no weld joint misalignment. Cross-sections of these welds are shown in Figures 3 to 6. The test parameters used to make these welds are shown in Tables 2 to 5.

With a closed root and a 2.4 mm (3/32 inch) thick land, a relatively high primary current of about 155 A was required to ensure root fusion. No torch oscillation was required. It had been shown in previous work /2/ that with no root opening, sound P-GTA root-pass welds could be made in all welding positions using a single set of welding parameters.

In the present work, weld joints with 3.2 mm (1/8 in), 4.8 mm (3/16in), and 6.4 mm (1/4 in) root openings were welded. Based on these test results, the following observations and conclusions were drawn for welding root openings up to 6.4 mm:

a) for a root opening at or greater than 1.6 mm (1/16 inch), torch oscillation across the weld face was required to produce sound root beads (information for welding 1.6 mm (1/16 inch) root openings was based on previous work at AECL/SPEL/2/);

b) relatively low primary current levels of 95 to 105 A and short dwell times of 0.3 to 0.4 seconds were required to avoid excessive melting of the root face while still ensuring complete side to side fusion;

c) a low background current of approximately 60 A was required to lower weld heat input across the gap in the weld joint; higher current levels caused excessive melting and lower current levels hampered the ability of the weld pool to accept the high wire feed rates required to fill the large opening;

d) the oscillation amplitude was set so that the torch oscillated approximately the same width as the root opening; the torch oscillated at a speed ranging from 3 to 4 mm/sec (7 to 9.5 inch/min);

e) high background wire feed rates of 8.3 to 14.9 mm/sec, which were often higher than the primary wire feed rates, were required during the excursion time to make up for the lack of base material in the root opening;

f) in the absence of weld joint misalignment, the AVC primary current sampling mode was preferred, which reduced excessive torch motion as the current changed between the primary and background levels and held a fixed torch position across the unstable and rapidly fluctuating weld pool;

g) in the presence of a 6.4 mm (1/4 inch) root opening, sound root-pass welds could only be made in the 1G and 3G (downhill) welding positions; in other welding positions the ability of the procedure to carry the largely unstable pool across the large root opening was hampered by gravity effects and our inability to properly position the wire feed into the weld pool, which was fluctuating in position.

2.3.3 Effects of Welding Position

In order to simulate all-position pipe welding, the welding trials were carried out on test plates in the 1G, 2G, 3G (uphill), 3G(downhill) and 4G welding positions. The following observations were made:

a) As the width of the root opening increased, the molten weld pool tended to lag behind the welding arc due to gravitational effects, particularly in the 3G(uphill) and 4G(overhead) welding positions;

b) for root openings at and greater than 3.2 mm (1/8 inch), an increase of primary welding current by approximately 5% and an increase of wire feed rate during the excursion time were preferred to maintain the size and stability of the molten weld pool when welding in the 3G(uphill) and 4G welding positions; consequently, the throat thickness of the deposit in these positions was much greater than in other positions.

c) In the horizontal welding position (2G) the gravity effect on the weld deposits of root welds in joints with no misalignment generally caused only a gentle sag in the cross-section. However, in weld joints with a misalignment of the plates the effect of the horizontal position was magnified, and the position of the higher plate (ie upper side or lower side) had to be

considered. In weld numbers 21 and 25 (see Figure 8) and in Table 7 it can be seen that a single set of parameters was successful in joining the plates despite the reversal of the upper/lower plate positioning.

2.3.4 Effects of Weld Joint Misalignment

In the present work, GTA root-pass welds were made with a 2.4 mm (3/32 in) misalignment and root opening ranging from 0 to 4.8 mm (3/16 in). The following observations were made:

a) continuous AVC sampling mode had to be used for adjusting the arc length during both primary (dwell) and background (excursion) current levels to compensate for the changes in height across the root face as the electrode traversed it;

b) for a weld joint consisting of a closed root and a mismatch of 2.4 mm, the optimum welding procedure consisted of the use of the continuous torch travel mode, a weave pattern of 3.2 mm amplitude and the continuous AVC sampling mode. Furthermore, the weave pattern also employed unequal dwell times for the misaligned plates (eg, 0.3 sec for higher side of the root face and 0.6 sec for the lower of the root face). These settings were required to ensure complete fusion of the lower root face as the torch weaved up and down over the ledge which was formed between the misaligned plates.

3.0 DISCUSSION

3.1 Acceptability of P-GTA Root-Pass Pipe Welds

Generally we believe that the root-pass welds produced using the welding procedures developed for each joint type (ie, each fit-up condition) and welding position will meet the requirements for a Class 1 Nuclear piping system. However, there are several practical implications concerning the shape of the internal root bead and the heavy oxide scale on the underside of the root bead that should be considered.

The maximum misalignment allowed at any one point around a joint by ASME Section III NB-4233 is 2.4 mm (3/32 in). It was shown that as weld joints containing misalignment of this magnitude were welded, a ridge was often formed on the underside of the root bead (see Figure 9). The height of this ridge was also enhanced as a result of weld sag, particularly when welding in the 1G (flat) and 2G (horizontal) welding positions in the presence of a large root opening. When welding a joint containing no root opening and a relatively large misalignment, it was shown that torch oscillation was required for root-pass welding to increase the width of the fusion and thus reduce the slope of the "weld ridge" (see Figure 7). No acceptance criterion is mentioned in NB-4233 concerning the root bead

profile on the inside of the circumferential pipe welds. It is, however, felt that some guidelines should be established concerning the acceptability of this profile of the inside root bead with regard to the following considerations: a) flow restriction/turbulence; b) fracture susceptibility and c) ultrasonic and radiographic inspectability of pipe joints in the presence of a ridge or a notch condition on the ID surface of the weld.

In the present work backing gas shielding was not used and a heavy oxide scale was consequently found on the inside surface of all the root beads (see Figure 10). It is perceived, however, that such an oxide scale might adversely affect the ultrasonic inspectability of the pipe weld root. It is therefore suggested that for pipe welding applications, consideration should be given to the use of internal inert gas shielding. In addition, another beneficial effect of internal shielding would be an increase in the weld pool's surface tension (caused by the removal of surface oxides), which would likely reduce somewhat the sharp angular changes in the profile.

3.2 Possible Enhancement of Weld Joint Fit-Up Tolerance with Adaptive Control of P-GTA Welding

It was shown that sound root-pass GTA welds could be made in all welding positions for a wide range of root opening/misalignment combinations by making appropriate compensating adjustments to the welding parameters and torch motion. Welding procedures were developed for the following weld joint fit-up conditions for the 1G, 2G, 3G(uphill), 3G(downhill) and 4G welding positions:

a) root opening - 0 to 4.8 mm (0-3/16 in),
b) misalignment - 0 to 2.4 mm (0-3/32 in).
c) any opening/misalignment combinations within the same tolerances,
d) root opening - 6.4 mm or 1/4 in (1G and 3G(downhill) positions only with no mismatch).

The present work appeared to demonstrate that add-on adaptive weld process capabilities could be introduced to existing mechanized GTA welding machines,, to produce sound root-pass welds under a wide range of varying weld joint fit-up conditions, which at present could only be welded using manual GTA welding techniques. Two essential adaptive control needs have been identified:

- joint position recognition to ensure (a) correct torch positioning, and (b) an oscillation amplitude for the weld torch equivalent to the root opening;

- joint feature recognition (eg root opening and misalignment) and, associated with this, a capability for real-time modification of the welding parameters.

3.3 Control Strategies for Adaptive Control P-GTA Root-Pass Pipe Welding

The test results of the present work and previous work at AECL/SPEL/2/ provide a basis for the development of a real-time control system for GTA root-pass welding of large diameter piping. A general flow chart of possible control algorithms for adaptive control GTA root-pass welding is shown in Figure 11.

The welding algorithms provide rules for selecting appropriate welding parameters according to the measured values of root opening or gap (RO), misalignment (M) and welding position (P). It is shown in Figure 11 that adaptive control P-GTA root-pass welding can be carried out utilizing the concept of "mini tolerance regions". Each region indicates a finite range of root opening/misalignment/welding position conditions that may be welded using a fixed set of welding parameters.

It is shown that if either or both the root opening and the misalignment exceed the allowable limits (ie, root opening >4.8 mm or 3/16 inch or misalignment >2.4 mm or 3/32 inch), welding would not be attempted.

It has been shown in the present work that compared to misalignment and welding position, changes of root opening have the most significant effect on the quality of P-GTA root-pass welds. In Figure 11, three mini tolerance regions of root opening have been defined (ie, RO1, RO2 and RO3). WP1, WP2 and WP3 are the base welding procedures for RO1, RO2 and RO3 respectively. Additional refinements to these primary procedures are then provided to account for the measured misalignment and for welding position.

As shown in Figure 11, welding procedure WP1 is used for welding a root opening less than 1.6 mm (1/16 inch). It has been illustrated in the present work, and previous work at AECL/SPEL/2/ (for the 1G and 2G positions only), that as long as joint geometry is constant there is no need for welding parameter adjustments to compensate for changes of welding position. Some adjustment is required, however, for changes in misalignment. For misalignment less than 0.8 mm (1/32 inch), the welding tests 1 and 2 parameters (see Table 2) can be used for WP1(M1). WP1(M2) and WP1(M3) are modified versions of WP1(M1) to compensate for increases in weld joint misalignment. WP1(M2) will likely involve an increase of the welding current to ensure full root penetration. With a further increase in misalignment, welding parameter adjustments in WP1(M3) would include a) introduction of lateral torch weave motion together with appropriate weave parameters and b) the initiation of the continuous voltage sampling mode.

WP2 and WP3 are welding procedures for mini tolerance regions R02 and R03 respectively (see Figure 11), which account for root openings ranging from 1.6 to 4.8 mm (1/16 to 3/16 inch). The present work and the previous work at AECL/SPEL/2/show that for welding root openings at or greater than 1.6 mm (1/16 inch), suitable adjustments to welding parameters must be made to avoid excessive melting of the root faces in order to form a sound root-pass weld. Welding parameter adjustments compensating for variations in root openings are shown in Section 2.3.2. Modifications to WP2 and WP3 would also be required to accommodate changes (see Section 2.3.4) in misalignment. Furthermore, it has been illustrated (see Section 2.3.3) that for welding root openings greater than 3.2 mm (1/8 inch), it is also necessary to compensate for changes in welding position. It was shown that compared to other welding positions, an increase of welding current and wire feed rate would be required when welding in the 3G(uphill) and 4G positions. It is assumed that for all-position pipe welding, similar adjustments to welding parameters would be required between the 4:30 and 10:30 welding positions (ie when welding in the clockwise direction), although this assumption still needs further experimental verification.

It should be noted that the experimental data reported herein only covered in part the various welding procedures (see Table 1) defined in Figure 11 (ie WP1(M1) etc). More tests will have to be performed to generate a complete data base, with the present results providing a good starting point. Figure 11 should be looked upon as a schematic representation of what appears to be a viable approach to establishing a real-time control system for P-GTA root-pass pipe welding.

4.0 GENERAL DISCUSSION ON THE DEVELOPMENT OF AN ADVANCED PIPE WELDING SYSTEM

For in-situ welding of large diameter piping, large weld joint fit-up variations would likely be encountered, particularly with pipe end tie-ins. The present work illustrates that some level of computer intelligence and sensor-based feedback must be incorporated into existing mechanized P-GTA welding systems to measure and adjust for changes of weld joint fit-up and welding positions. The details of an extensive work program directed at the development of such an advanced pipe welding system are described in a recent OHRD report/1/. A modular work program is currently underway at OHRD, with major activities in several technical areas, including sensors,, computer controls, and advanced welding processes.

In the area of sensor technology, a prototype computer vision system was designed and built at OHRD to demonstrate the laser/solid state camera approach for detecting weld joint geometry and fit-up conditions/4/. It was shown that through analysis performed on the digitized image of the weld joint, significant features of the weld geometry could be identified and located. These features included the opening center, opening height, opening width and misalignment. It is perceived that a laser-based vision system will likely be an integral part of the advanced welding system. The sensor will be placed about 25 mm ahead of the welding torch. During

welding, vision data concerning the weld joint features (eg location of the upper edges of the root faces) ahead of the weld pool will be collected and sent to the central computer for adaptive weld process control.

In order to reduce the amount of in-house development effort, it was decided to purchase a state-of-the-art laser sensor system and to continue investigation of this approach to providing feedback control in automated pipe welding. Currently, a laser/solid state camera sensor system is on order from Modular Vision System (MVS) Inc., Quebec. This system was developed at the Industrial Materials Research Institute (IMRI) of NRC. Receipt of the sensor system at OHRD is expected by July 1987. The sensor system will be designed and constructed according to the specification prepared by technical staff of OHRD. Upon receipt of the sensor system, preliminary work will be carried out in 1987 to evaluate the capabilities of the as-received sensor system to detect features of butt joints with V- and J-groove preparations. These features include joint edges, root opening, and high/low misalignment. The measuring range and resolution of the sensor system will also be assessed. Further work will include computer software development so that the vision data can be applied to adaptive control of welding applications.

In 1979, the Welding Unit of the Metallurgical Research Department began work, with the support of Generation Serices Department (now Mechanical Design Department, D&D-Gen), to establish a fundamental capability in applying computer control to welding. Since 1985, the Welding Unit has undertaken a major R&D program, in collaboration with Hydro-Quebec (IREQ) and with co-funding from the Canadian Electrical Association (CEA), to develop a prototype robotic system for the remotely-controlled in-situ repair welding of hydraulic turbine runners/5/. The technologies being developed in the CEA project, particularly concerning computer-controlled robotic welding and tracking, will serve as a basis for the development of a weld process controller (central computer) for P-GTA root-pass pipe welding.

It is perceived that this central computer will be one of the key components of an advanced pipe welding system. According to vision data received from the sensor system, the computer will send appropriate command instructions to the weld head and the power source for real-time welding torch positioning and welding parameter control. The computer will contain computer programs with rules for interactive adjustment and optimization of torch position and welding parameters depending on the varying weld joint fit-up and welding position. The experimental data and the control strategy reported herein will form the basis for the development of these computer programs for adaptive control of P-GTA root pass welding.

Besides development of sensor and computer control technology, the present work also suggested a number of worthwhile add-on capabilities to existing mechanized P-GTA pipe welding systems.

During the welding trials of the present work, minor on-line adjustments to the wire feed guide were found to be necessary to ensure the correct entry of the filler wire into the weld pool (ie entry angle and position). Thus, a remotely driven wire feed guide manipulator, along with a vision system that would permit a clear view of the weld pool and the filler wire during welding, may be needed in an advanced pipe welding system.

Presently, the only one way to control heat input individually on each side of the weld joint is through adjustments to the dwell times, which adversely affects the travel motion when the stepping travel mode is used. It is therefore suggested that the implementation of a separate welding current control for each side dwell would be advantageous. This feature would be very helpful when welding uneven thickness joint preps or when the misalignment is large.

5.0 CONCLUSIONS

5.1 All-position mechanized P-GTA root-pass welding procedures have been developed, that permit welding of the following weld joint fit-up conditions (assuming a consistent machined land thickness):

- root opening - 0 to 4.8 mm (0 to 3/16 inch)
- misalignment - 0 to 2.4 mm (0 to 3/32 inch)
- any root opening/misalignment combinations within the same tolerance ranges.

5.2 In-situ root-pass pipe welding, which presently can only be carried out manually, may also be performed using the mechanized welding technique by incorporating appropriate adaptive control capabilities into existing mechanized P-GTA welding systems. It has been illustrated that weld joint fit-up tolerances for mechanized root-pass welding can be significantly widened by implementing the following adaptive control features:

- joint position recognition to ensure correct positioning and appropriate oscillation amplitude of the weld torch relative to the weld joint;

- joint feature recognition (eg root opening and misalignment) along with real-time control of welding process parameters to compensate for changes in fit-up and welding position.

5.3 The algorithms or rules for interactive adjustment and optimization of weld head position and welding parameters, depending on the varying welding conditions, have been defined. These control algorithms, together with a welding data base, can be used to develop computer programs for adaptive control of P-GTA root-pass welding.

5.4 The requirements and guidelines for the development of a laser-based sensor system have been established. The main function of this sensor system is to collect weld joint geometry information from the area just ahead of the weld torch during welding, and to send this information to the weld process controller for adaptive control of the welding process.

5.5 Further study will be required in order to evaluate the beneficial effects of the implementation of a backing gas shield in terms of root inspectability and root profile.

5.6 Acceptance criteria should be established for the internal profile of root beads on circumferential pipe welds, taking into consideration flow restriction/turbulence effects, effects on long term mechanical integrity, and the inspectability of the root area.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Mr. D. Farmery for preparation of samples for metallographic examination. Thanks are also extended to Mr. G. Poon, Mr. K. Yiu and Mr. M.J. Tinkler for useful discussions on this study.

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REFERENCES

1. Maak, P.Y.Y. and Tinkler, M.J., "Proposal for the Development of Advanced Pipe Welding in Ontario Hydro", Ontario Hydro Research Division Report 86-308-H, December, 1986.

2. Grant, I.M., "Joint Fit-Up Tolerances and Adaptive Control for Mechanized Gas Tungsten Arc Pipe Root Pass Welding", AECL/SPEL Report IR 607, April, 1986.

3. Grant, I.M., Maak, P.Y.Y. and Tinkler, M.J.," An Assessment of Automated Pipe Welding - Literature Survey", Ontario Hydro Research Division Report 86-27-K, May, 1986.

4. Mader, D.L., "Computer Vision for Robotic Welding", Ontario Hydro Research Division Report 86-229-K, September, 1986.

5. Tinkler, M.J. and McNabb, S.C., "Development of a Robotic System for the In-Situ Repair of Hydraulic Turbine Runners", Ontario Hydro Research Division Report 85-121-H, April 1985.

TABLE 1 - SUMMARY OF P-GTA ROOT-PASS WELDING TRIALS

Welding Test No	Root Opening mm (in)	Misalignment mm (in)	Welding Position*	Data Base **
1 & 2	0	0	3G (uphill), 4G	WP1 (M1)
3 to 7	3.2 (1/8)	0	All positions	WP2 (M1)
8 to 12	4.8 (3/16)	0	All positions	WP3 (M1)
13 & 14	6.4 (1/4)	0	1G, 3G(downhill)	-
15 to 19	0	2.4 (3/32)	All positions	WP1 (M3)
20 to 25	3.2 (1/8)	2.4 (3/32)	All positions	WP2 (M3)
26 to 30	4.8 (3/16)	2.4 (3/32)	All positions	WP2 (M3, P1) WP3 (M3, P2)

* All positions - 1G, 2G, 3G(uphill), 3G(downhill), 4G

** See Figure 11 for definitions of WP1, WP2 and WP3, etc.

TABLE 2 - WELDING PARAMETERS OF TESTS 1 & 2
(0 ROOT OPENING AND 0 MISALIGNMENT)

Test No	Position	CURRENT H.Pulse	CURRENT L.Pulse	CURRENT PPS	CURRENT Pulse W.	Voltage (H.Pulse sample mode)	Travel Speed (mm/min)	Wire Speed (mm/s) H.Pulse	Wire Speed (mm/s) L.Pulse
1	3G(up)	155	70	1	50%	9.5	3.5	7.3	4.3
2	4G	155	70	1	50%	9.5	3.5	7.3	4.3

TABLE 3 - WELDING PARAMETERS OF TESTS 3 TO 7
(3.2 MM ROOT OPENING AND 0 MISALIGNMENT)

Weld	Position	Current (Amps) Dwell	Current (Amps) Trav	Voltage (Dwell sampled AVC)	Travel Speed (mm/min)	Wire Feed Speed (mm/s) Dwell	Wire Feed Speed (mm/s) Trav	Oscillation Dwell Exc Times (secs)	Oscillation Time (secs)	Oscillation Amplitude (mm)
3	1G	95	60	9.5	31	16.5	8.3	0.3	0.8	3.2
4	4G	105	60	9.5	31	16.5	8.3	0.3	0.8	3.2
5	3G (up)	95	60	9.5	31	16.5	8.3	0.3	0.8	3.2
6	2G	95	60	9.5	31	16.5	8.3	0.4	0.8	3.2
7	3G(down)	95	60	9.5	31	16.5	8.3	0.4	0.8	3.2

TABLE 4 - WELDING PARAMETERS OF TESTS 8 TO 12
(4.8 MM ROOT OPENING AND 0 MISALIGNMENT)

Weld	Position	Current (Amps) Dwell	Current (Amps) Trav	Voltage (Dwell sampled AVC)	Travel Speed (mm/min) Dwell	Travel Speed (mm/min) Ave	Wire Feed Speed (mm/s) Dwell	Wire Feed Speed (mm/s) Trav	Oscillation Dwell Exc Times (secs)	Oscillation Time (secs)	Oscillation Amplitude (mm)
8	1G	95	60	9.5	101	27	8.3	8.3	0.4	1.2	4.8
9	3G(down)	95	60	9.5	101	27	8.3	8.3	0.4	1.2	4.8
10	3G(up)	105	60	9.5	101	27	8.3	13.4	0.4	1.2	4.8
11	4G	105	75	9.5	101	27	8.3	14.9	0.4	1.2	4.8
12	2G	95	60	9.5	101	27	8.3	12.6	0.4	1.2	4.8

TABLE 5 - WELDING PARAMETERS OF TESTS 13 AND 14
(6.4 MM ROOT OPENING AND 0 MISALIGNMENT)

Weld	Position	Current (Amps)		Voltage (Cont. sampled AVC)	Travel Speed (mm/min)		Wire Feed Speed (mm/s)		Oscillation		
		Dwell	Trav		Dwell	Ave	Dwell	Trav	Dwell Times (secs)	Exc Time	Amplitude (mm)
13	1G	95	60	9.5	101	21	8.3	13.4	0.4	1.8	6.4
14	3G(down)	95	60	9.5	101	21	8.3	16.5	0.4	1.8	6.4

TABLE 6 - WELDING PARAMETERS OF TESTS 15 TO 19
(0 ROOT OPENING AND 2.4 MM MISALIGNMENT)

Weld	Position	Current (Amps)		Voltage (Cont. sampled mode.)	Travel Speed (mm/min)	Wire Feed Speed (mm/s)	Oscillation			
		Dwell	Trav				High Side Dwell (sec)	Low Side Dwell (sec)	Exc Time (sec)	Amplitude (mm)
15	1G	145	90	9.5	28	8.3	0.3	0.6	0.8	3.2
16	2G	145	90	9.5	28	8.3	0.3	0.6	0.8	3.2
17	4G	165	100	9.5	28	8.3	0.3	0.6	0.8	3.2
18	3G(dn)	145	90	9.5	28	8.3	0.3	0.6	0.8	3.2
19	3G(up)	165	100	9.5	28	8.3	0.3	0.6	0.8	3.2

TABLE 7 - WELDING PARAMETERS OF TESTS 20 TO 25
(3.2 MM ROOT OPENING AND 2.4 MM MISALIGNMENT)

Weld	Position	Current (amps)		Voltage (Cont. sampled AVC)	Travel Speed (mm/min)	Wire Feed Speed (mm/s)		Oscillation		
		Dwell	Trav			Dwell	Trav	Dwell Times (sec)	Exc Time (sec)	Amplitude (mm)
20	1G	105	60	9.5	26	10.0	14.9	0.3	0.4	1.6
21	2G	105	60	9.5	26	8.3	12.6	0.3	0.4	1.6
22	4G	105	60	9.5	23	10.0	14.9	0.3	0.4	1.6
23	3G(up)	105	60	9.5	23	10.0	13.4	0.3	0.4	1.6
24	3G(dn)	105	60	9.5	26	6.7	9.2	0.3	0.4	1.6
25	2G	105	60	9.5	26	8.3	12.6	0.3	0.4	1.6

TABLE 8 - WELDING PARAMETERS OF TESTS 26 TO 30
(4.8 MM ROOT OPENING AND 2.4 MM MISALIGNMENT)

Weld	Position	Current (amps)		Voltage (Cont. sampled mode)	Travel Speed (mm/min)		Wire Feed Speed (mm/s)		Oscillation		
		Dwell	Trav		Dwell	Ave	Dwell	Trav	Dwell Times (secs)	Exc Time	Amp (mm)
26	1G	115	70	9.2	101	22	16.5	14.9	0.4	1.6	4.8
27	4G	135	70	9.2	101	22	16.5	14.9	0.4	1.6	4.8
28	3G(dn)	115	70	9.5	101	22	14.9	12.6	0.4	1.6	4.8
29	2G	115	70	9.5	101	22	16.5	14.2	0.4	1.6	4.8
30	3G(up)	115	70	9.2	101	18	16.5	14.2	0.3	1.6	4.8

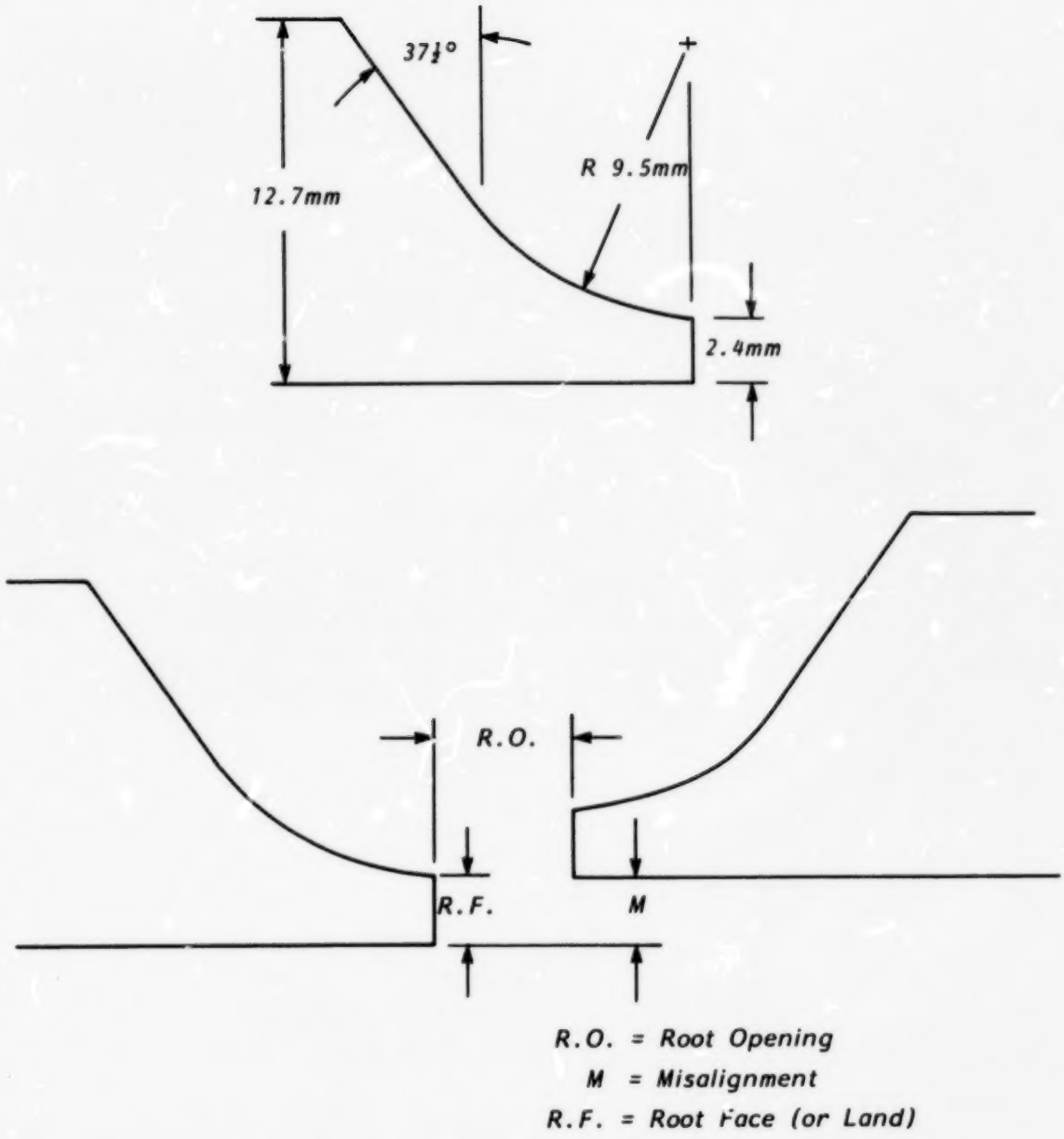


FIGURE 1
JOINT PREPARATION AND FIT-UP DEFINITIONS

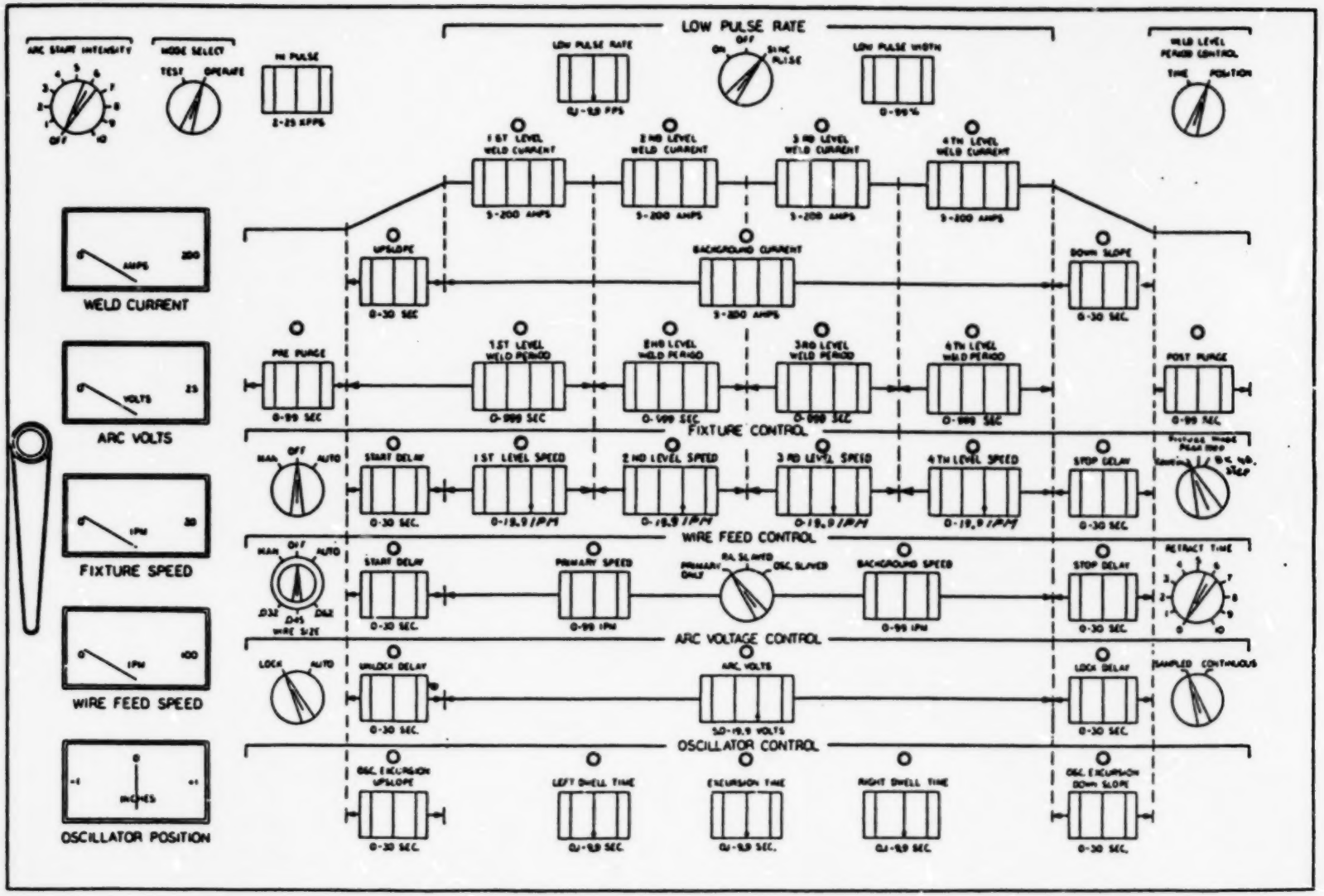
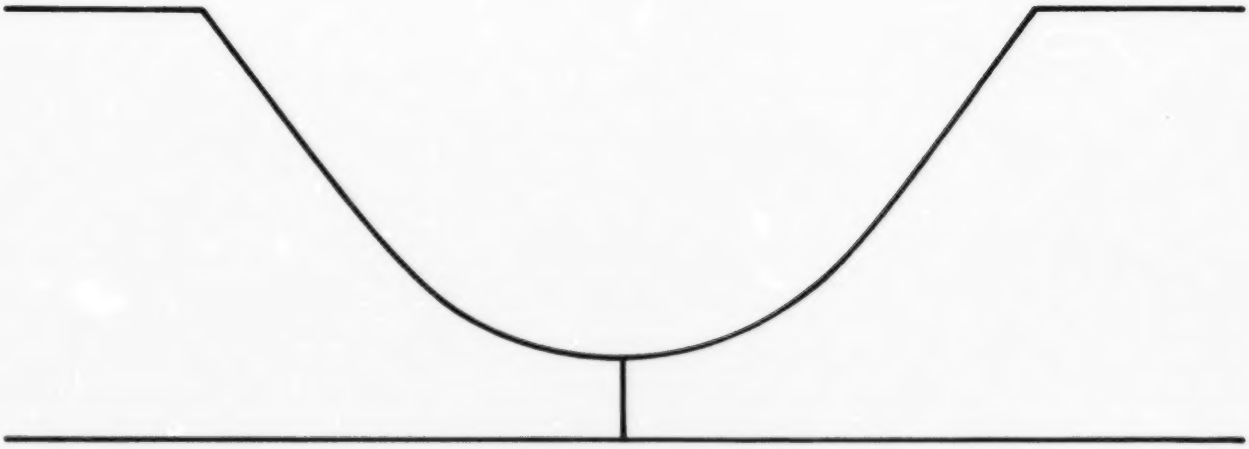
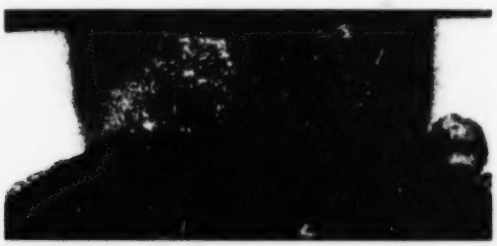


FIGURE 2
DETAIL OF CONTROL PANEL

174844-RD
87-125



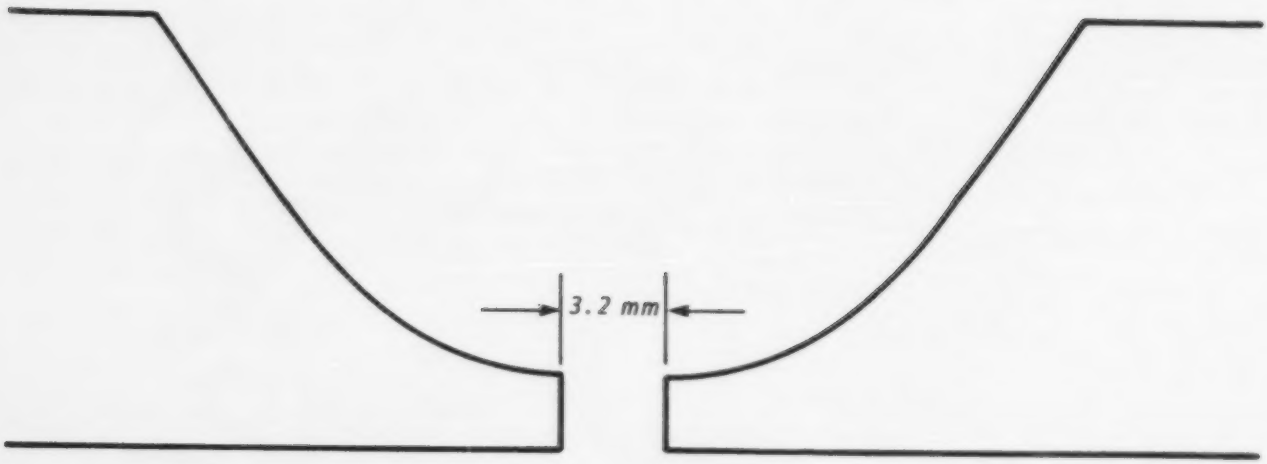
1-3Gup



2-4G

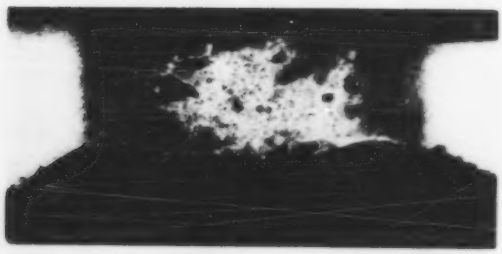
FIGURE 3

CROSS-SECTIONS OF WELD SAMPLES 1 AND 2
(IDEAL FIT-UP CONDITIONS)
(Mag 5x)

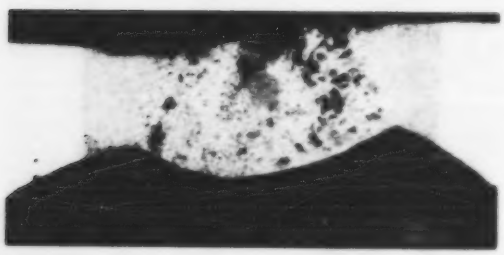


3-1G

6-2G



4-4G



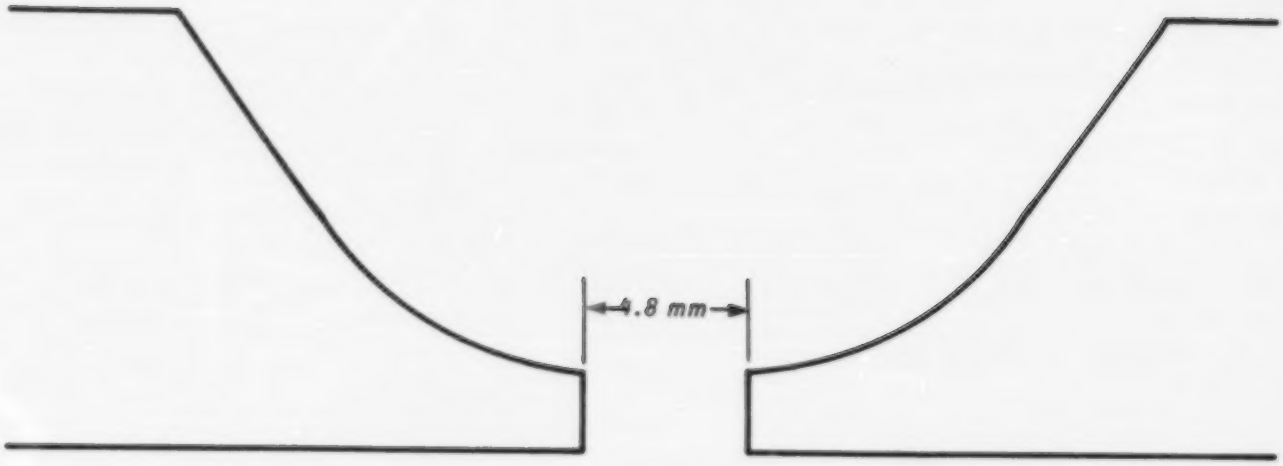
5-3Gup

7-3Gdn

FIGURE 4

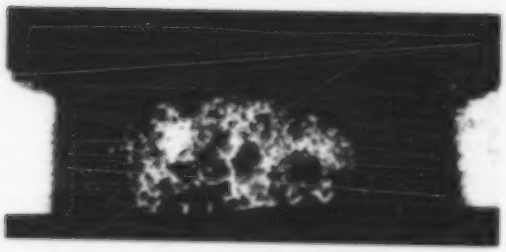
CROSS-SECTIONS OF WELD SAMPLES 3 TO 7 SHOWING EFFECTS OF 3.2 mm (1/8 in) ROOT OPENING (Mag 5x)

173650-RD

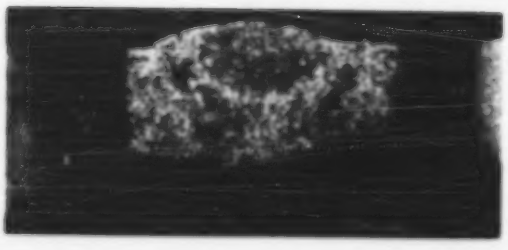


8-1G

11-4G



9-3Gdn



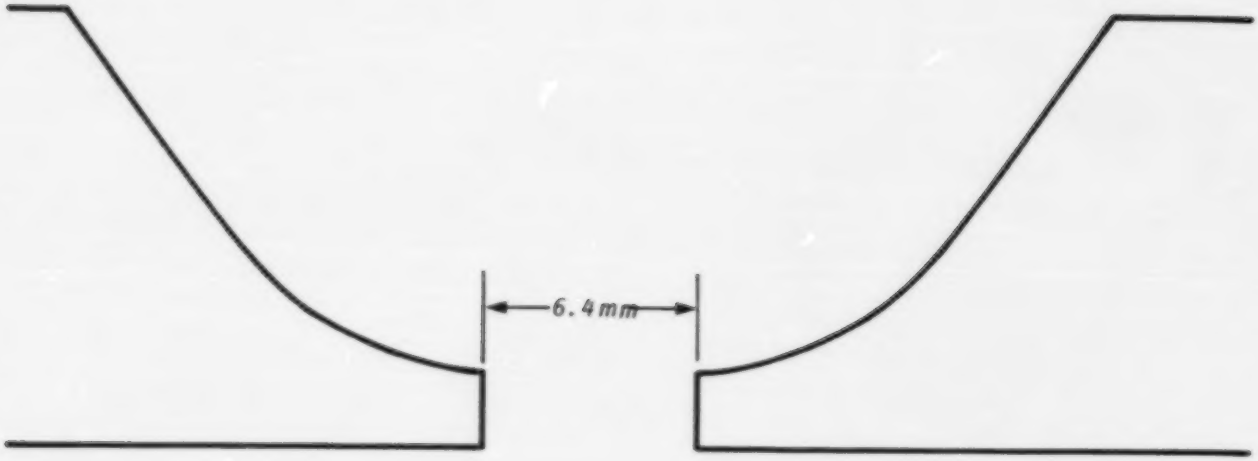
10-3Gup

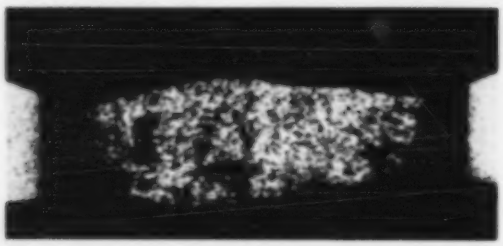
12-2G

FIGURE 5

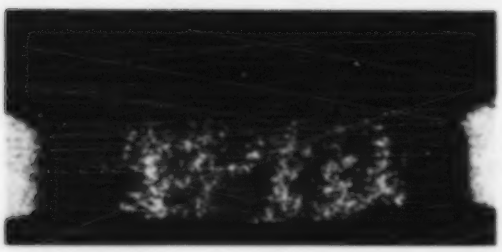
CROSS-SECTIONS OF WELD SAMPLES 8 TO 12 SHOWING EFFECTS OF 4.8 mm (3/16 in) ROOT OPENING
(Mag 5x)

173651-RD





13-1G

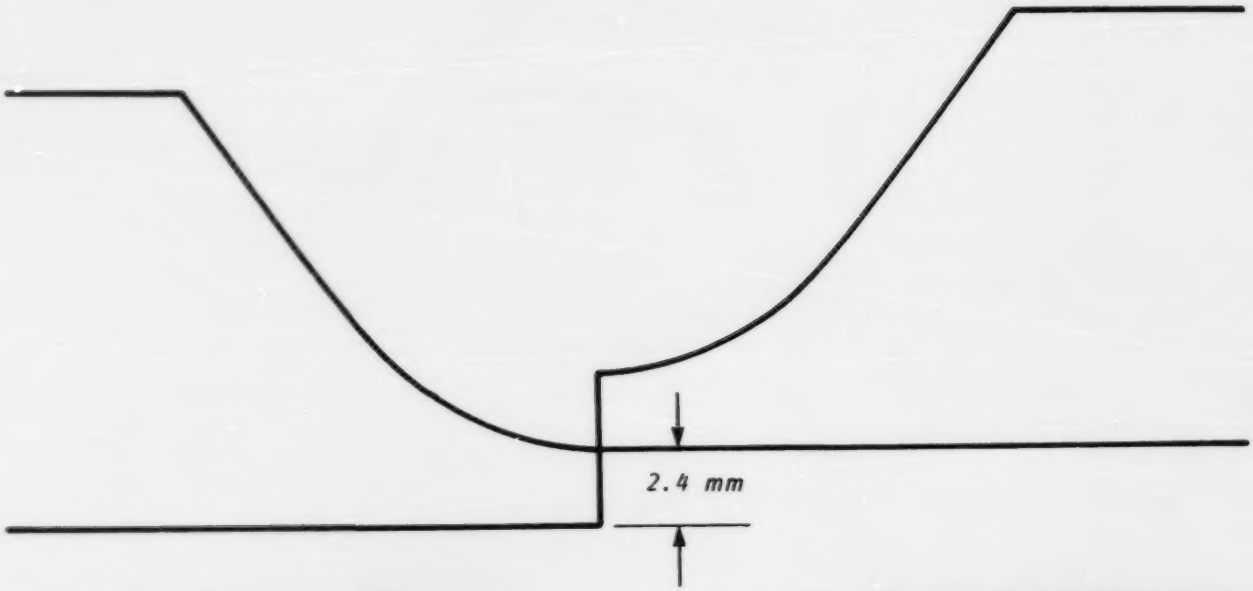


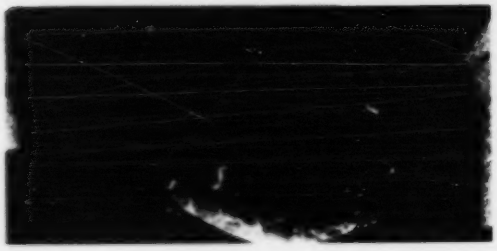
14-3Gdn

FIGURE 6

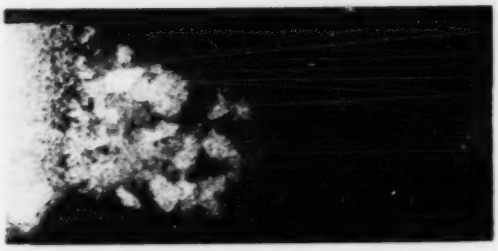
CROSS-SECTIONS OF WELD SAMPLES 13 AND 14 SHOWING EFFECTS OF 6.4 mm (1/4 in) ROOT OPENING (Mag 5x)

173652-RD

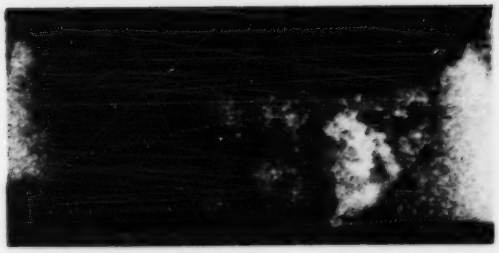




15-1G

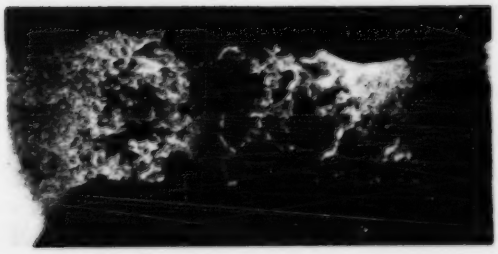


19-3Gup



18-3Gdn

16-2G

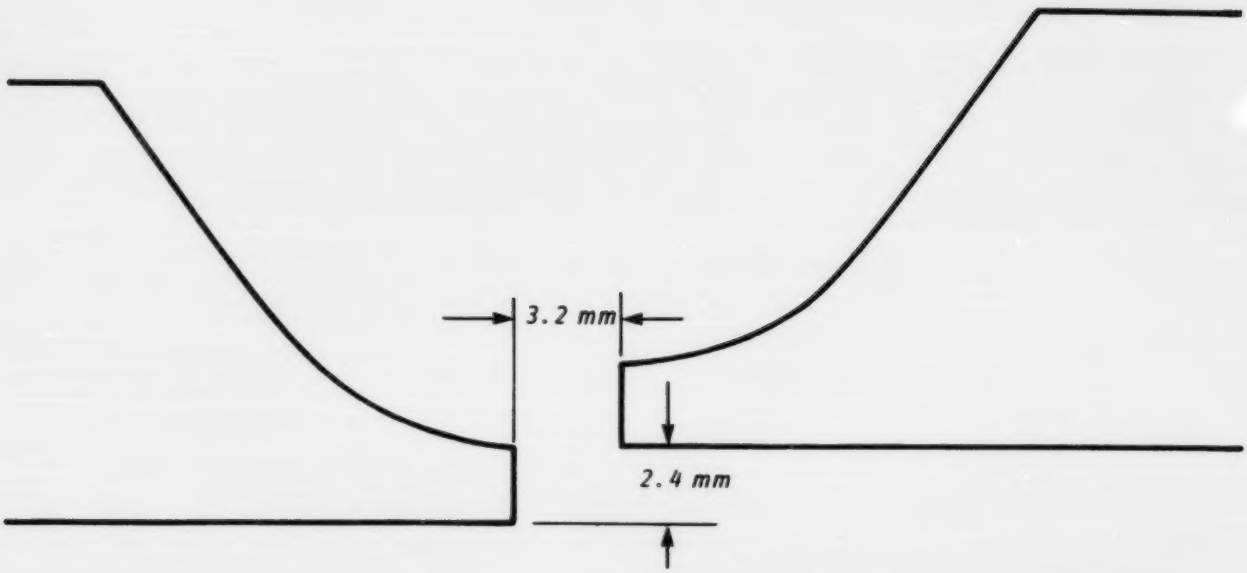


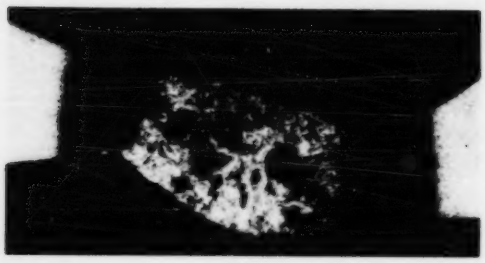
17-4G

FIGURE 7

CROSS-SECTIONS OF WELD SAMPLES 15 TO 19 SHOWING EFFECTS OF 2.4 mm (3/32 in) MISALIGNMENT (Mag 5x)

173655-RD

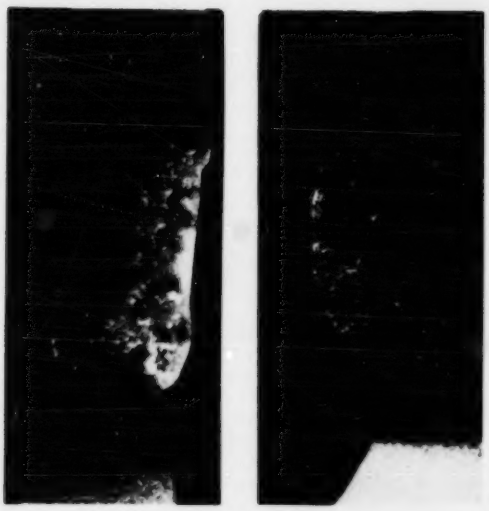




20-1G

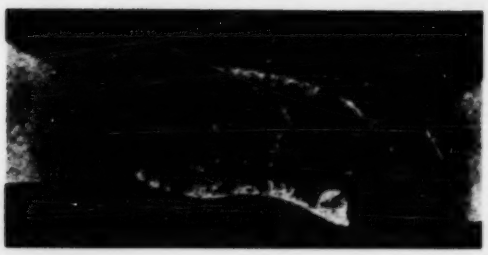
22-4G

23-3Gup



21-2G

25-2G

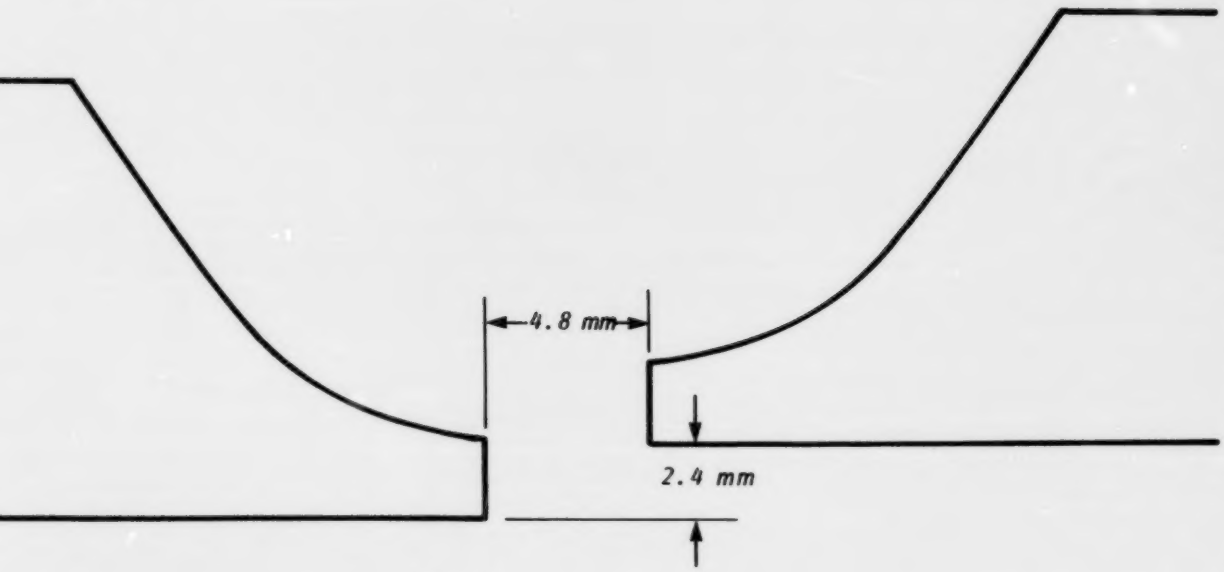


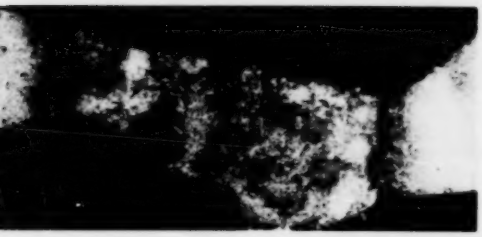
24-3Gdn

FIGURE 8

CROSS-SECTIONS OF WELD SAMPLES 20 TO 25 SHOWING EFFECTS OF 3.2 mm (1/8 in) ROOT OPENING AND 2.4 mm (3/32 in) MISALIGNMENT
(Mag 5x)

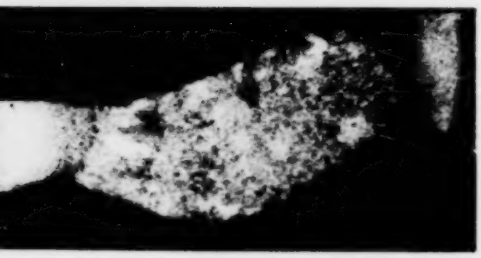
173653-RD



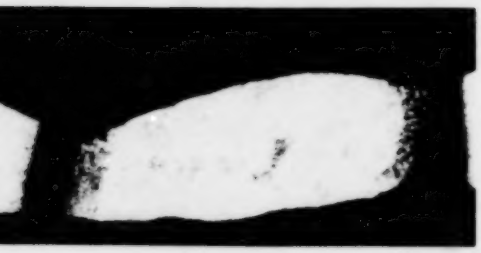


26-1G

29-2G



27-4G



28-3Gdn

30-3Gup

FIGURE 9

CROSS-SECTIONS OF WELD SAMPLES 26 TO 30 SHOWING EFFECTS OF 4.8 mm (3/16 in) ROOT OPENING AND 2.4 mm (3/32 in) MISALIGNMENT (Mag 5x)

173656-RD

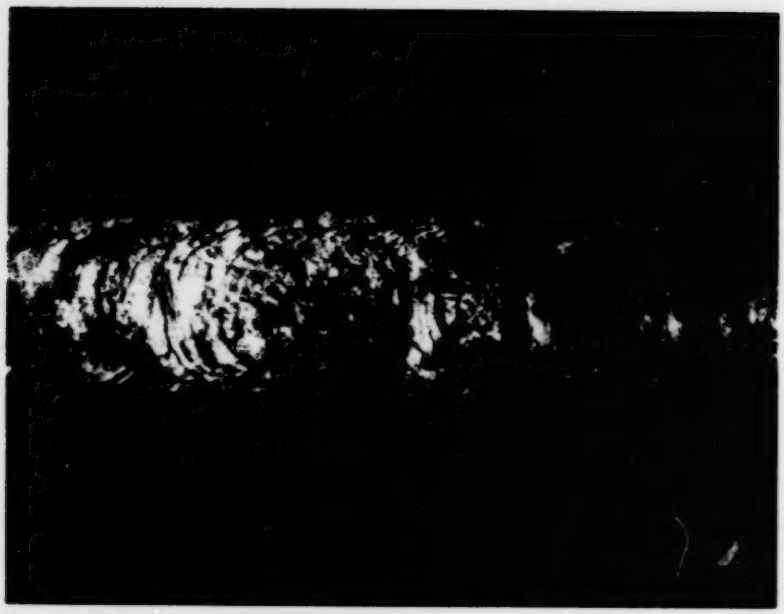


FIGURE 10

A TYPICAL P-GTA ROOT BEAD SHOWING
HEAVY OXIDE SCALE ON THE INSIDE BEAD SURFACE
(Mag 3x)

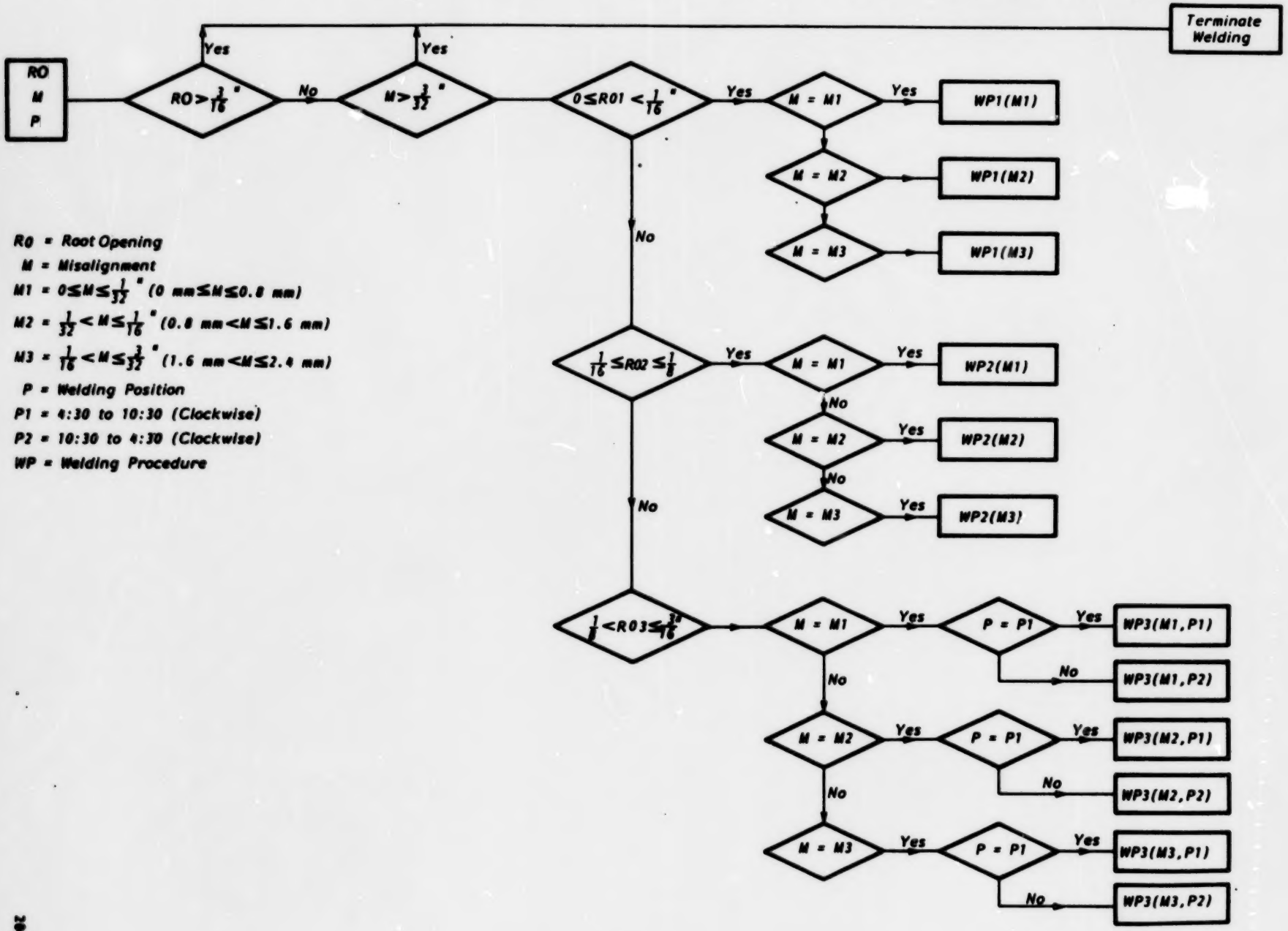


FIGURE 11

RECOMMENDED CONTROL ALGORITHMS FOR ADAPTIVE CONTROL OF P-GTA ROOT-PASS WELDING

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